ASSESSMENT OF ABDOMINAL MUSCLE EXERCISES IN NON-PREGNANT, PREGNANT AND POSTPARTUM SUBJECTS, USING ELECTROMYOGRAPHY

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The purpose of this study was to analyse, by electromyographic technique, abdominal muscle activity in exercises commonly advocated as being effective in improving abdominal muscle performance. In general, exercises from the lying position were found to involve the rectus abdominis and oblique muscles more than those exercises from standing, sitting or kneeling positions. Further, among exercises from lying, 'trunk on legs' and 'trunk plus legs' involved these muscles more than 'legs on trunk' exercises. With pregnancy and in the puerperium there was a change in the pattern of abdominal muscle involvement in exercises from the lying position, suggesting that the traditional division of exercise lists into 'antenatal' and 'postnatal' is not optimal: the demarcation "circumnatal" (around the time of birth) and "abnatal" (remote from the time of birth) would appear to be more appropriate. Details are given of the method of assessment of exercises, data analysis and interpretation of results. The findings have implications for the selection of exercises for clinical use in obstetric physiotherapy.

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The belief that certain exercises produce the muscle involvement claimed has been handed down from one generation of physiotherapists to the next and many have accepted traditional lists of exercises without question. Extravagant claims have been made based on clinical impressions rather than on a sound scientific basis. The Obstetric Study Group of Victoria* undertook this investigation to analyse some of the more popular exercises used for abdominal muscle strengthening and to show experimentally, by means of electromyography, whether a given exercise involved the abdominal muscles and which of a series of exercises involved those muscles the most; changes in muscle response during pregnancy and the puerperium were also investigated. It was anticipated that the findings of this study would provide a scientific basis for the planning of antenatal and postnatal exercise programmes. Thus exercises which might have definite therapeutic possibilities could be separated from others which were solely based on outdated concepts and perpetuated by convention.

BASIS OF TECHNIQUE

Electromyography

The electrical changes across skeletal muscle membranes, which trigger the contractile process, give rise to an electrical field which can be sampled by either needle electrodes inserted into the muscle or by surface electrodes attached firmly to the skin overlying the muscle. The potential so sampled, after suitable amplification, may be recorded either on an oscilloscope or on a moving paper chart and is known as the electromyogram.

The electromyogram obtained with voluntary contraction is contributed to by many motor units firing asynchronously. In general, the more units activated and/or the greater their rate of firing, the greater the amplitude and complexity of the pattern, always with the proviso that the instrument amplification is constant and that electrode siting and effectiveness of electrical contact with the skin are constant. The integrated electromyogram may be used to quantitate this amplitude and complexity. Technically, it is the area under the curve of the rectified wave form. This can be obtained mechanically or electronically and given a numerical value in arbitary units. Alternatively, integration may be carried out by visual scanning of a series of electromyographic records and placing a given electromyogram into an arbitary grade Thus the electromyogram recorded from a muscle during a series of manoeuvres can be used as an index of the relative involvement of that muscle in those manoeuvres, that is, of the number of active motor units and their discharge frequency. Sample electromyographic records are shown in Figure 1.

Relationships between electromyographic activity, that is, electrical activity of muscle and the mechanical forces produced are complex: they have been the subject of many papers and much controversy over the last two or three decades. Bayer and Flechtenmayer (1950), Inman, Ralston, Saunders, Feinstein and Wright (1952) and Lippold (1952) showed a linear relationship between the integrated electromyogram and muscle tension during voluntary isometric contraction. This principle has been confirmed many times but there have been reservations as to whether it applies to all muscles (Bigland and Lippold, 1954) or to the complete range of voluntary effort within a given muscle (Kuroda, Klissouras and Milsum, 1970; Lewillie, 1973). For isotonic contraction, the relationship between electrical and mechanical parameters is linear only if the velocity of contraction is held constant and even at constant velocity it varies according to whether the muscle is shortening or lengthening (Bigland and Lippold, 1954; Komi, 1973; Bigland-Ritchie and Woods, 1974). In addition, electromyographic/mechanical relationships are influenced by fatigue (Edwards and Lippold, 1956; Lippold, Redfern and Vuco, 1960).

The exercises studied in this paper were a complex mixture of isometric contraction and of concentric and eccentric isotonic contractions at inconstant velocities. Thus even if electronic integration of electromyograms had been available it would not have been possible to predict the mechanical counterpart with any degree of quantitative precision.

METHODS

(1) Recording of Electromyograms

Muscles studied: The muscles studied were the left rectus abdominis, the left external and internal oblique, and the right external oblique. The recti and the external oblique muscles being large and superficial present no problem in the siting of surface electrodes. The internal oblique muscles, on the other hand, are accessible only in the limited triangular areas bounded by the lateral edge of the rectus sheath, the inguinal ligament and the line joining the anterior superior iliac spine to the umbilicus.

Electrodes: For this study surface electrodes were chosen in preference to needle electrodes because a general overall view of electrical activity of a large muscle was required rather than a detailed analysis of motor unit activity. The electrodes used were low-profile recessed silver discs (8 millimetres) mounted in rubber grommets and filled with electrode jelly. The merits of various types of surface electrodes are discussed by Geddes (1972). Validation of the use of surface electrodes for electromyographic recording from the abdominal muscles is given by Floyd and Silver (1950).

Preparation for recording was carried out with the subject lying on a couch. The skin overlying the muscles to be studied was rubbed briskly with mildly abrasive electrode jelly to lower the electrical resistance and all surplus jelly removed. The electrodes were filled to the brim with electrode jelly then firmly taped in position, either with a plastic adhesive strapping or a self adhering foam The electrodes were placed in pairs over the four muscles for simultaneous electromyographic recording: a single electrode on the trunk acted as the earth connection. One pair were placed widely separated (15 centimetres) along the mid-longitudinal axis of the rectus abdominis muscle, thus sampling electromyographic activity of the muscle as a whole rather than of individual segments. Electrodes on the left external oblique muscle were placed along the line of its fibres about 10 centimetres apart; a symmetrical pair was placed on the right external oblique muscle; electrode spacing on the internal oblique muscle was limited to 2.5 centimetres.

Recording apparatus: The amplification and recording system used was a four channel Beckman Type RB Dynograph. Muscle action potentials, as recorded through the skin, are of the order of a millivolt· they were amplified to several hundred volts to drive the pens of the recorder. Pen movements were recorded on chart paper which moved at known speed: 5 millimetres per second was used in these experiments. The four channels displayed simultaneously the electromyographic activity of the four abdominal muscles under study (Figure 1).

At the start of each subject's record, the gain on each amplification channel was adjusted to give a convenient size electromyographic response, as judged by responses to a few preliminary manoeuvres by the subject. The numerical value of the gain or the fact that it may vary from channel to channel was of no consequence: assessment of records was made only by comparisons within one channel (Methods (3)).

(2) Exercises and Subjects

Exercises, Pilot study: Exercises were chosen from traditional lists in current use and included wide representation of exercises performed from crook-lying, supine, side-lying, sitting, standing and four-foot kneeling positions (for details refer Appendix I).

Exercises, Main series: This comprised an extended list of exercises all from the lying position (exercises from this position had been shown in the pilot study to involve the abdominal muscles much more than exercises from other starting positions). The list included traditional exercises and some modifications introduced to test some commonly held beliefs. The main series list of twenty-one exercises from the lying position was subdivided as follows:

Section 1: Trunk movements on the legs ('trunk on legs')

straight movements
diagonal movements
side-bending movements

Section 2: Leg movements on the trunk ('legs on trunk')

Section 3: Trunk and leg movements performed simultaneously ('trunk plus legs')

The exercises are referred to in the text by a code number, followed by an abbreviated description in brackets. A fuller description of each exercise in the main series will be found in Appendix II.

Subjects: The subjects of this investigation were grouped into four categories: non-pregnant, 38 weeks gestation, 5 days and 6 weeks postpartum. The non-pregnant subjects were mainly students or physiotherapists of childbearing age. In the pilot study four patients from private physiotherapy practice were followed right through their obstetric sequence: 38 weeks gestation, 5 days and 6 weeks postpartum: there were six subjects in the non-pregnant group. This 'follow through' technique was not feasible for the main study: instead a relatively large number of different women at the various stages were tested. There were thirty subjects in each of the four categories, that is, a total of one hundred and twenty women were tested using the main series exercises. Subjects in the 38 weeks gestation and 6 weeks postpartum categories were patients from private physiotherapy practice. Subjects in the 5 days postpartum category were from the Royal Women's Hospital, Melbourne.

Conduct of tests: Exercise instructions were usually given to subjects by the same member of the study group who endeavoured to use the same tone of voice and speed of instruction each time. Main series exercises were held for 5 seconds, the subject resting for 20 seconds before the next exercise. Each exercise was performed once and the same sequence of exercises was used for each subject. The fact that the order of exercises was not randomised did not appear to cause any artificial trend in results which might have been interpreted as due either to fatigue or to learning (Figure 3).

(3) Assessment of Electromyographic Records

The record of an individual subject comprised several metres of four channel electromyographic tracing showing in turn the response to each exercise on the list (a part of such a tracing is shown in Figure 1). The trace from the first channel was visually scanned and the responses grouped into three grades of electromyographic activity designated 'highest', 'middle' and 'lowest' — as judged by the amplitude and frequency of the action potential discharge. This was done by firstly grouping together 'highest', then 'lowest', the remainder being 'middle grade' electromyographic activity. Clear cut lines of demarcation were looked for but were not always easy to define — in cases of doubt the response was deemed 'middle grade'.

The procedure was repeated with the other three channels. For each of the four muscles under test a given exercise was associated with a relative grade of electromyographic activity, that is, a relative degree of motor unit involvement. Because of the subjective nature of the assessments it was essential for at least four people, working in pairs or singly, to scrutinise each record.

It must be stressed that comparison of electromyographic amplitude and frequency is valid only within one channel and for one specific siting of electrodes, that is, in terms of the four channel electromyographic record, comparisons can only be made longitudinally, that is, within one channel (Figure 1). Although it is not valid to compare one channel (that is, one muscle) with another in terms of electromyographic activity, it is legitimate to compare them in terms of 'relative grades'. For example a very small electromyographic trace produced by a certain exercise may still be relatively 'highest grade' for that particular channel (muscle) and this exercise/muscle situation can legitimately be compared with other exercise/muscle situations which are also deemed relatively 'highest grade' in their own particular channels.

Thus, if a large number of patients is studied, it is legitimate to add up the number of occasions on which a given exercise produced electromyographic activity deemed to be of relatively 'highest grade' for a given channel, that is, for a given muscle. The assumption is made that the more frequently this occurs, the more common is a high degree of motor unit involvement of that muscle, that is, the 'better' the exercise.

(4) *Reduction of Data*

Information from the assessment of electromyographic records was charted in three ways:

Bar Charts

For each of the four muscles under test in each of the four subject categories, bar charts were constructed with the number of subjects out of thirty on the vertical axis and the exercise code numbers on the horizontal axis, that is, a total of sixteen bar charts of which one is shown as a sample (Figure 2) The solid block above a given exercise code number represents the number of subjects out of thirty for whom that exercise had been assessed as having 'highest grade' electromyographic activity. The corresponding outline above the solid block represents the number out of thirty for whom that exercise had been assessed as having 'middle grade' electromyographic activity. The space remaining above the outline represents the number out of thirty for whom that exercise had been assessed as having 'lowest grade' electromyographic activity.

Individual exercise rating

This is illustrated in Figure 3 and was derived from the sixteen bar charts. Exercises which had ten or more subjects out of thirty showing 'highest grade' electromyographical activity were arbitrarily rated as 'good'; those whose combined 'highest' and 'middle grades' totalled ten or more were rated 'moderate' and those whose combined 'highest' and 'middle grades' totalled less than ten out of thirty were rated 'poor'. It should be noted that the three ratings are relative rather than absolute, there had already been considerable pruning of the standard list of exercises as a result of the pilot study.

Merit ranking

This is illustrated in Table 1, and is also derived from the sixteen bar charts. However, Table 1 gives greater detail than Figure 3 in that the actual number of people within each grade of electromyographic activity has been quoted. The exercises listed in Table 1 include all those which were rated 'good' and which have been used in the construction of Figure 3. In addition, figures for some of the exercises rated 'moderate' are included where the total number of 'highest' and 'middle grades' of electromyographic activity was relatively high, that is, at least twenty out of thirty subjects. For each muscle and each subject category the exercises have been arranged, as far as mathematically possible, in merit order. It will be noted that some sections in Table 1 contain many more exercises than others, that is, the range of effective exercises is much wider for some muscles and in some subject categories than others.

RESULTS AND DISCUSSION

Pilot Study

The electromyographic tracings recorded in the pilot study indicated that exercises from the lying position involved the abdominal muscles much more than exercises starting from four-foot kneeling, sitting or standing positions. For this reason, the main series concentrated on exercises from the lying position. Bearing down, suggested by Basmajian (1978) as a useful manoeuvre for strengthening the external oblique muscles, did not rate highly in the pilot study and was not investigated further in the main series

Main Series

The results in this section represent the final analysis of lying exercises, exercises from other starting positions having been eliminated as relatively ineffective by the pilot study. The 'reduced data' interpreted in this section was produced by the techniques outlined in Methods: 4

General Observations

Within the lying exercise series, the 'trunk on legs' group and the 'trunk plus legs' group appeared to be more effective than the 'legs on trunk' group, effectiveness being judged by the number of 'good' and 'moderate' occurrences in Figure 3 It should be noted when studying Figure 3 that 'poor' does not decry an exercise when it occurs unilaterally in an exercise taken first to the left and then to the right, for example, Exercise 14 (crook-lie: side bending) and Exercise 16 (supine: side bending). Only three exercises in the main series were uniformly rated 'poor': they were Exercise 18 (supine: single leg raise); Exercise 24 (crook-lie: knee rolling) and Exercise 26 (supine: chin on chest, single leg raise). In contrast, no one single exercise was uniformly 'good' for each muscle tested for every subject category. The nearest approach to this was Exercise 6 (supine: hands clasped behind head, curl) which was rated 'good' for rectus abdominis muscle in all subject categories, 'good' for external and internal oblique muscles in the non-pregnant category and was never less than 'moderate' in any situation. Exercise 8 (supine: trunk raise with straight back) was also rated 'good' or all abdominal muscles in the non-pregnant category and either 'good' or 'moderate' for all muscles in the other categories.

Considering individual muscles, for the rectus abdominis muscle Exercise 6, as stated above, was uniformly rated 'good', in contrast, the findings with the oblique muscles were not so clear cut. The only exercise uniformly rated 'good' for the oblique muscles was Exercise 14L for the left external oblique muscle (crook-lie: side bending to left). This finding is considered further in the discussion.

Changes in abdominal muscle response during pregnancy and the puerperium

The most noticeable change with pregnancy was the marked increase in the number of effective exercises in pregnant as compared with non-pregnant women, this can be seen by examination of Figure 3. Thus for the rectus abdominis muscle, additional 'straight, trunk on legs' exercises were rated as 'good'; 'diagonal, trunk on legs' and 'trunk plus legs' exercises, which in the non-pregnant subjects only rated 'moderate', were rated 'good' in the 38 week gestation category. For the oblique muscles, more exercises of all groups except 'legs on trunk' were rated 'good'. In general, a greater number of exercises of the 'trunk on legs' and 'trunk plus legs' group were effective in the 38 week gestation category compared with non-pregnant subjects: in contrast, no such change in status occurred in the 'legs on trunk' group of exercises.

In the 5 days postpartum category there were already indications of a return toward the non-pregnant pattern. This change was particularly noticeable in the 'diagonal, trunk on legs' exercises and 'trunk plus leg' exercises and least noticeable in the 'side bending, trunk on legs' exercises. By 6 weeks postpartum there was almost complete return to the non-pregnant pattern.

These changes during and after pregnancy are further illustrated for rectus abdominis muscle in Figure 4. In this figure of superimposed bar charts, the distribution of 'highest grade' electromyographic activity in the non-pregnant category is compared in turn with the 38 weeks gestation, 5 days postpartum, and 6 weeks postpartum categories.

Testing the validity of some commonly held beliefs

Examination of Figure 3 enables one to assess some of the commonly held beliefs regarding involvement of abdominal muscles. These 'beliefs', posed as questions in the following section, were not generally upheld by the electromyographic criteria used in this study.

Are the abdominal muscles involved more when trunk raising is performed with curl than with a straight back?

A comparison was made between Exercise 4 (supine: curl) and Exercise 8 (supine: trunk raise with straight back). refer Figure 3. In the non-pregnant category Exercise 8 (straight) had a superior rating to Exercise 4 (curl), at 38 weeks gestation the ratings were equal, at 5 days post-partum and 6 weeks postpartum the ratings progressively moved towards the non-pregnant pattern. At no stage did exercise 4 (curl) have a superior rating to Exercise 8 (straight) that is, in terms of abdominal muscle involvement, no advantage was gained by curling.

Does anchoring the feet 'inhibit' abdominal muscle action?

A comparison was made between Exercise 9 (supine: feet anchored, curl) and Exercise 4 (supine: curl): refer Figure 3. In the non-pregnant and 6 weeks postpartum categories ratings were equal for Exercise 9 (feet anchored) and Exercise 4 (feet not anchored). Exercise 9 (feet anchored) never had an inferior rating to Exercise 4 (feet not anchored), that is, anchoring the feet did not 'inhibit' abdominal muscle activity.

If the subject is unable to sit up from the supine position does the use of a ramp make the exercise more effective?

A comparison was made between Exercise 4 (supine: curl) and Exercise 10 (starting from a 40 degree ramp, curl). Exercise 10 (with a ramp) never had a superior rating to Exercise 4 (without a ramp): refer Figure 3. Thus there was no greater abdominal muscle involvement when the ramp at 40 degrees was used, that is, the ramp had not made the exercise more effective In fact Exercise 10 (with a ramp) was the only exercise in the 'trunk on legs' group that was rated 'poor' for all muscles in the non-pregnant category, and for the internal oblique muscles throughout. In contrast, considerable electromyographic activity was produced in an attempt to sit up from the supine position even when very little movement was achieved

Is double leg raise one of the most effective abdominal muscle exercises?

Exercise 21 (supine: double leg raise) was rated 'good' only once, namely, for the left internal oblique in the non-pregnant category; in all other instances, it was rated 'moderate'. In contrast, Exercise 8 (supine: trunk raised with straight back) was rated 'good' ten out of sixteen times (four subject categories with four muscles under text); Exercise 6 (supine: hands clasped behind head, curl) and Exercise 12 (crook-lie: diagonal curl) were both rated 'good' nine times and so on, as illustrated in Figure 3. Thus, in comparison with other exercises in this series, double leg raise was certainly not one of the most effective ways of producing electromyographic activity in the abdominal muscles.

Does bending the knees increase abdominal muscle activity during trunk raising?

There are five comparisons that relate to this question:

i Exercise 2 (crook-lie: curl) compared with Exercise 4 (supine: curl).

ii Exercise 12L (crook-lie: diagonal curl to left) compared with Exercise 13L (supine: diagonal curl to left).

iii Exercise 12R (crook-lie: diagonal curl to right) compared with Exercise 13R (supine: diagonal curl to right).

iv Exercise 14L (crook-lie: side bending to left) compared with Exercise 16L (supine. side bending to left).

v Exercise 14R (crook-lie: side bending to right) compared with Exercise 16R (supine. side bending to right).

This means that there are five by four by four, that is, eighty comparisons of ratings. Examination of Figure 3 indicates that in eight of these the knees-bent exercise had a superior rating to the knees-straight exercise; in one, the reverse was true and in the remaining seventy-one, the grades were equal. Thus, the verdict is slightly in favour of bent knees, and this mainly with respect to the oblique muscles.

Is an abdominal muscle exercise improved by incorporation of pelvic tilt?

In the pilot study pelvic tilt, on its own or with prolonged expiration, produced relatively little electromyographic activity in the abdominal muscles. Nevertheless, all but two of the exercises in the main series were carried out from the lying with pelvic tilt position, to avoid hyperextension of the lumbar spine, (Kendall, Kendall and Wadsworth, 1971). Trunk curl with bent knees and trunk curl with straight knees were both carried out with and without the commencing instruction to tilt the pelvis, specifically to test the role of prior pelvic tilt in the exercises. The comparisons which relate to this question are Exercise 2 (crook-lie: curl) and Exercise 4 (supine: curl), both of which involve prior pelvic tilt, compared respectively with Exercise 1 (crook-lie, without prior pelvic tilt, curl) and Exercise 3 (supine: without prior pelvic tilt, curl). Examination of Figure 3 indicates that addition of pelvic tilt improved the rating of the exercise in only 1 out of 32 possible comparisons. In contrast, exercises without pelvic tilt rated more highly than those with pelvic tilt in 4 out of 32 possible comparisons (these were all in the 5 days postpartum category) Thus in terms of electromyographic activity of abdominal muscles, trunk curl was not improved by the inclusion of pelvic tilt.

Muscle Bracing

Experiments were carried out in cooperation with Mrs Beryl Kennedy, in which the main series exercises were modified by the incorporation of the muscle bracing technique (Kennedy, 1965). It is claimed that in this technique the oblique abdominal muscles play an important role in increasing intra-abdominal pressure which stabilises the lumbar spine. No striking enhancement of the electromyographic records resulted from the inclusion of 'bracing', but the series was far too brief to be conclusive one way or the other and it would repay further study.

GENERAL DISCUSSION

Exercise Ratings

Throughout this series of experiments, it always proved easier to judge which was the 'lowest grade' of electromyographic activity from a given recording sequence than to distinguish between 'highest' and 'middle grades'. Thus it was easier to eliminate 'poor' exercises than to decide between 'good' and 'moderate' exercise ratings. These arbitary ratings, explained in detail in Methods (4), were as follows: 'good' equals 'highest grade' electromyographic activity in ten or more subjects out of thirty; 'moderate' equals 'highest' plus 'middle grade' electromyographic activity in ten or more subjects out of thirty; 'poor' equals 'highest' plus 'middle grade' electromyographic activity in fewer than ten subjects out of thirty.

In exercises with a uniformly 'poor' rating, namely Exercise 18 (supine: single leg raise), Exercise 24 (crook-lie: knee rolling) and Exercise 26 (supine: chin on chest, single leg raise), 'highest grade' electromyographic activity never occurred more than two out of thirty times for any muscle in any subject category. In exercises with a 'good' rating, 'lowest grade' electromyographic responses were generally few. The least favourable combination which came into the arbitrary 'good' rating was ten 'highest' plus nine 'middle' plus eleven 'lowest grades' electromyographic activity; more commonly, in a 'good' exercise, the 'lowest grade' occurred only in zero to six out of thirty subjects.

The problem of whether it is better to recommend an exercise producing 'middle grade' electromyographic activity in the large majority of subjects in a category or, if it is better to recommend an exercise which produces a 'higher grade' of activity, that is, greater muscle involvement but in fewer people, is almost a philosophical one and as such devoid of simple solution.

Symmetry

Diagonal and side bending exercises were conducted first to the left and then to the right. The different responses from the left external oblique as comnpared with the right external oblique were qualitatively what might be expected from the known action of these muscles. However, the 'balance' between left and right was not always quantitatively precise. This raises the question as to whether there is a genuine inbalance or lack of symmetry in response, or does it merely reflect the lack of precision in the technique. A specific example, Exercise 14, is taken to illustrate this point (see Figure 3). For the left external oblique, Exercise 14L (crook-lie. side bending to left) was rated 'good' in all subject categories. One might expect that the corresponding exercise to the right, that is, Exercise 14R would be rated 'poor' for the left external oblique and this expectation was borne out in all subject categories. However, the expectation that reciprocal 'good'/'poor' pattern would occur for the right external oblique was not fully realised; Exercise 14L was rated 'poor' for the right external oblique in all subject categories, but Exercise 14R rated 'good' only for the 5 days postpartum category — for the others it was only 'moderate'. Whether this is a true lack of symmetry is hard to say — at least the results, one side compared with the other, are in the expected direction even though not entirely of the expected magnitude. Floyd and Silver (1950) in their series of electromyographic recordings from abdominal muscles of young men also found some difference in response between the left and right side.

One can look further at this problem by considering the more detailed information in Table 1. Take for example the 6 weeks postpartum category; Exercise 14L produces in left external oblique muscle 'highest grade' electromyographic activity in ten subjects, and 'middle grade' in thirteen subjects out of the thirty studied and thus just makes the arbitrary classification of a 'good' exercise. In comparison, the reciprocal movement, Exercise 14R, produced in the right external oblique muscle 'highest grade' electromyographic activity in only seven out of thirty subjects and thus does not rank as 'good'. However, with twenty one subjects, it produced 'middle grade' electromyographic activity and is thus well into the 'moderate' ranking ('highest' plus 'middle grades' in more than ten out of thirty subjects).

If one considers the total of 'highest' and 'middle grades' electromyographic activity as an index of an effective exercise, in contrast to the much more clearly delineated 'lowest grade' electromyographic activity as denoting a relatively ineffective exercise, then we have a slightly different picture. Then Exercise 14L (crook-lie: side bending to left) — would be effective for left external oblique muscle ten plus thirteen, that is, twenty three times out of thirty and Exercise 14R (crook-lie: side bending to right) would be effective for right external oblique muscle seven plus twenty one, that is, twenty eight times out of thirty Thus the imbalance in favour of the left is no longer apparent — if anything, it has swung the other way.

The reciprocal nature of to left and to right exercises is also evident in Figure 2. In Exercises 12 and 13 ('diagonal, trunk on legs') the number of subjects in whom electromyographic activity in the right external oblique muscle is of 'highest grade' is greater when the exercise is carried out to the left than when it is carried out to the right. In Exercises 14 and 16 ('side bending, trunk on legs') the reverse is true, that is, the number of subjects in whom electromyographic activity in the right external oblique muscle is of 'highest grade' is greater when the exercise is carried out to the right than when it is carried out to the left These findings substantiate the accepted role of the oblique muscles in these circumstances, and incidently, help validate the technique for reduction of data that has been employed.

Possible causes of conflicting results in the literature

There is a fairly extensive literature on assessment of abdominal skeletal muscle involvement using electromyographic techniques, but very little uniformity among the findings. Relevant research papers include Flint and Gudgell (1965), Floyd and Silver (1950), Girardin (1973), Gutin and Lipetz (1971), Lipetz and Gutin (1970), De Sousa and Furlani (1974), Walters and Partridge (1957). A recent review, Clarke (1976), incorporates findings from forty-four papers. Some variant of the sit-up commonly occurs as a recommended manoeuvre for testing or for strengthening the abdominal muscles. However, there are varying reports of the influence on sit-ups of the position of the limbs and of the relative involvement of trunk and hip flexors.

The question therefore arises, as to why electromyographic studies of abdominal muscle involvement in various manoeuvres have provided so much conflicting information. Three main groups of research workers have been interested, anatomists, physical educationalists, and physiotherapists. From personal observations, it appears that the latter two groups tackle exercises in quite different ways, physical education manoeuvres are usually carried out very much more briskly than physiotherapy manoeuvres. This is exemplified by tracings obtained by Gillam, I.H. (1972, personal communication), where the very brisk physical education type sit-up produced three distinct components in the electromyogram from the rectus abdominis muscle: an initial burst of action potentials associated with a rapid concentric contraction, an almost silent pause as the vertical position was held and a final burst of action potentials associated with the rapid eccentric contraction of the return movement In marked contrast, the physiotherapy type trunk raising manoeuvre usually involves slow, steady progression to and return from a new position (which may or may not be fully vertical). Thus the abdominal muscle action potential discharge is often continuous during the whole manoeuvre, though it may fluctuate in intensity.

Thus variations in speed of carrying out a manoeuvre, the endless minor variations of detail as to how an exercise is performed, together with age, sex and physique differences, mean that different authors are not looking at absolutely identical problems and hence legitimate comparisons between one author and another are not easily made.

Finally, in any study, it is absolutely essential that electromyographic comparisons are made only between one muscle and itself without change in electrode conditions or amplification, that is, the only variable allowable is the exercise manoeuvre under study. It is not always absolutely clear that all authors have adhered to this principle, this too makes interpretation and comparison of results difficult.

Changes during and after pregnancy

There were marked changes in the pattern of exercise ratings in the 38 weeks gestation category as compared with non-pregnant subjects. many more exercises were rated 'good' in the pregnant group (Figure 3). The responses in the 5 days postpartum category were beginning to revert to the non-pregnant pattern, and by 6 weeks postpartum this reversion was almost complete. It would be of interest to examine in greater detail the time course of these changes and to consider possible explanations. The influence of sex hormones on abdominal muscle electromyographic activity, evoked by postural or respiratory manoeuvres, was described by Kawakami (1954): he found, for example, that progesterone depressed electromyographic activity and oestradiol enhanced it. It would seem likely that any such influence arising from sex hormone changes during and after pregnancy would be manifest whatever exercise was being used and thus have no bearing on the assessment of the relative effectiveness of exercises. Maybe the explanation of the changing patterns in pregnancy should be sought in terms of changes in muscle mechanics.

Selection of abdominal muscle exercises for clinical use

The importance of abdominal muscle work, such as trunk raising, and of pelvic floor exercises has recently been stressed by Spence (1978). Her survey indicated that rectus abdominis muscle strength and endurance were not good and that the majority of patients failed to carry out the prescribed exercise routines after discharge from hospital. Spence advocates the need for stronger abdominal muscle work, especially in the postnatal period. In this present study (Figure 3 and Table 1) it was noted that certain exercises which achieved 'good' or 'moderate' ratings were subjectively considerably more strenuous than those widely used in the past in obstetric physiotherapy practice. However, if a patient finds an exercise too strenuous or unacceptable for any reason whatsoever, it may deter her from regular practice. Therefore, in planning an exercise programme, the physiotherapist should keep in mind that there is a wide choice of exercises with 'good' or 'moderate' ratings from which selection may be made to suit the individual patient's needs.

It should be remembered that this present study is concerned only with abdominal muscles, no evaluation of the exercises with respect to effects, either favourable or adverse, on other body components can be implied.

It would appear from our study that the common practice of dividing exercises into antenatal and postnatal lists is not utilising the optimal line of demarcation. Thus non-pregnant and 6 weeks postpartum subject categories clearly had similar rating patterns (Figure 3 and Figure 4); 38 week gestation and 5 days postpartum categories, although by no means identical, were more like each other than they were like the non-pregnant or 6 weeks postpartum category. Perhaps a more appropriate demarcation would be "circumnatal" and "abnatal", that is, "around the time of birth" and "remote from the time of birth".

Bearing in mind all the points raised in this section of the discussion, it is recommended that physiotherapists study carefully the detailed charts of electromyographic involvement of abdominal muscles (Figure 3 and Table 1) and select from the exercises with 'good' and 'moderate' ratings those which they deem most suitable for any given individual patient.

SUMMARY

1 The purpose of this study was to analyse by electromyographic technique abdominal muscle activity in exercises commonly advocated as being effective in improving abdominal muscle performance.

2 A data processing technique is described which circumvents the problem of the invalidity of direct inter-channel comparison of electromyographic recordings.

3 Electromyograms were recorded only from the left rectus abdominis muscle, both external oblique muscles and the left internal oblique muscle. The rating in this study of a given exercise as 'poor' does not preclude the possibility of it having value with respect to improved performance of some other muscle, for example, those of the pelvic floor.

4 In general, exercises from the lying position were found, by electromyographic criteria, to involve the rectus abdominis and oblique muscles more than those from standing, sitting or kneeling positions. Further, among exercises from lying, 'trunk on legs' and 'trunk plus legs' exercises involved these muscles more than 'legs on trunk' exercises.

5 Detailed charts (Figure 3 and Table 1) indicate the relative effectiveness, as judged by electromyographic grading, of 21 exercises from the lying position, based on the analysis of data from a sample of 120 subjects in non-pregnant, 38 weeks gestation, 5 days and 6 weeks postpartum categories.

6 The charts have been used in assessing six 'commonly held beliefs' with respect to exercises from the lying position: in general they have not been upheld by this electromyographic study.

7 The charts and Figure 4 show clearly that with pregnancy and in the puerperium there is a change in the pattern of abdominal muscle involvement in exercises from the lying position. There is similarity in muscle involvement between the 38 weeks pregnant and the 5 days postpartum categories: both differ distinctly from the non-pregnant and the 6 weeks postpartum categories This suggests that the traditional division of exercise lists into 'antenatal' and 'postnatal' is not optimal: perhaps the most appropriate demarcation would be "circumnatal" (around the time of birth) and "abnatal" (remote from the time of birth).

8 Problems associated with the selection of exercises for clinical use are discussed and the recommendation made that obstetric physiotherapists select from the detailed charts (Figure 3 and Table 1) exercises with 'good' or 'moderate' ratings, bearing in mind the special needs of their own patients.

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Brief accounts of the pilot study and of the ongoing results of the main series have been presented by various members of the Obstetric Study Group of Victoria at seminars and at meetings of the Australian Physiotherapy Association.

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APPENDIX I

Exercises studied in the Pilot Study

A descriptive list of exercises, from various starting positions, is given below.

Explanation of terms

Crook-lying. lying on back, arms by sides, knees bent, feet flat on couch.

Supine: lying on back, arms by sides, legs straight.

Four-foot kneeling: on hands and knees.

Pelvic tilt: a specifically instructed flattening of the lower back by tightening abdominal and buttock muscles.

Curl: keeping chin on chest, shoulders and trunk raised in sequence to curve the body forward, attempting to reach a position midway between horizontal and vertical.

Bearing down: abdominal straining.

Timing

Exercises were carried out slowly and each was held in turn for 10, 20 and 30 seconds, interspersed with 15 seconds rest periods

A From Crook-lying Position

* Pelvic tilt.
* Pelvic tilt with prolonged expiration.
* Pelvic tilt, slide legs down to supine position whilst maintaining pelvic tilt.
* Pelvic tilt, keeping chin on chest, arms forward to raise shoulders just clear of couch.
* Pelvic tilt, arms forward, curl.
* Pelvic tilt, arms forward, curl diagonally to the left. As above to the right.
* Pelvic tilt, keeping chin on chest, raise shoulders just clear of the couch, slide left hand towards left ankle. As above to the right.
* Pelvic tilt, raise left leg to 10 degrees. As above to 45 degrees. As above to 90 degrees.
* Holding knees to chest, with hands under thighs, breathe in, hold breath then bear down.

B From Supine Position

* Pelvic tilt, raise both legs to 10 degrees. As above to 45 degrees. As above to 90 degrees.
* Pelvic tilt, keeping chin on chest, raise left leg to 10 degrees. As above to 45 degrees. As above to 90 degrees.
* Pelvic tilt, keeping chin on chest, arms forward to raise shoulders just clear of couch.
* Pelvic tilt, arms forward, curl.
* Pelvic tilt, keeping chin on chest, arms forward to raise trunk to the vertical position.
* Pelvic tilt, arms forward, curl diagonally to the left. As above to the right

C From Side-lying Position

* Raise head, uppermost arm and leg, slide hand towards ankle.

D From Sitting Position

* Keeping knees straight and arms by side, rotate trunk as far as possible to the left. As above to the right.
* With fingers hooked together in front of chin, elbows bent and out at shoulder level, breathe in, hold breath then bear down, attempting at the same time to pull the fingers apart

E From Standing Position

* Breathe in, hold breath then bear down.
* Trunk backward bend as far as possible.
* Pelvic tilt.
* Rise on toes, pelvic tilt. As above with crossed legs.

F From Four-foot Kneeling Position

* Keeping chin on chest, pelvic tilt, round the back.

* denotes start of an exercise

APPENDIX II

Exercises studied in the Main Series

A descriptive list of the twenty-one exercises from the lying position is given below, together with the code number used in the text and figures. Those numbers appearing with the suffix L or R indicate that the movement was to the left or to the right respectively. Phrases in brackets are the abbreviations used in the text. The few gaps in the code numbering are of no experimental significance.

Explanation of terms

'Crook-lie': lying on back, arms by sides, knees bent, feet flat on couch.

'Supine': lying on back, arms by sides, legs straight.

'Pelvic tilt': a specifically instructed flattening of the lower back by tightening abdominal and buttock muscles.

'Curl': keeping chin on chest, shoulders and trunk raised in sequence to curve the body forward, attempting to reach a position midway between horizontal and vertical.

Timing

Exercises were carried out slowly, the ultimate position of each exercise being held for 5 seconds, with 20 seconds rest periods between each exercise.

Section I Trunk Movements on the Legs ('trunk on legs')

i straight movements: code numbers 1-10

ii diagonal movements: code numbers 12, 13

iii side bending movements: code numbers 14, 16

1 Crook-lie: without prior pelvic tilt, arms forward, curl. (crook-lie, without prior pelvic tilt: curl).

2 Crook-lie: pelvic tilt, arms forward, curl. (crook-lie: curl).

3 Supine: without prior pelvic tilt, arms forward, curl. (supine, without prior pelvic tilt: curl).

4 Supine: pelvic tilt, arms forward curl. (supine. curl).

5 Supine: pelvic tilt, fold arms across chest, curl.

6 Supine: pelvic tilt, clasp hands behind head keeping elbows back, curl. (supine: hands clasped behind head, curl).

8 Supine: pelvic tilt, arms forward, keeping trunk straight and head back attempt to raise head and trunk to midway position. (supine· trunk raise with straight back).

9 Supine· pelvic tilt, arms forward, feet anchored, curl. (supine: feet anchored, curl).

10 Lying on couch with backrest raised to 40 degrees, legs straight, pelvic tilt, arms forward, curl. (starting from a 40 degree ramp: curl).

12 Crook-lie: pelvic tilt, arms forward, curl diagonally to the left. As above to the right. (crook-lie: diagonal curl).

13 Supine: pelvic tilt, arms forward, curl diagonally to the left. As above to the right (supine: diagonal curl)

14 Crook-lie: pelvic tilt, keeping chin on chest, raise shoulders just clear of the couch, slide left hand towards left ankle. As above to the right. (crook-lie: side bending).

16 Supine: pelvic tilt, keeping chin on chest, raise shoulders just clear of the couch, slide left hand towards left ankle. As above to the right. (supine· side bending)

Section II Leg Movements on the Trunk ('legs on trunk')

Code numbers 18-25

18 Supine. pelvic tilt, raise left leg to 45 degrees. (supine: single leg raise).

21 Supine: pelvic tilt, raise both legs to 45 degrees. (supine: double leg raise).

22 Supine: pelvic tilt, arms sideways to shoulder level, keeping left leg straight raise it as far as possible, then across towards the right outstretched hand. As above, right leg to left outstretched hand.

24 Crook-lie: pelvic tilt, keeping shoulders flat and knees together, roll knees to the left then to the right, return to midline. (crook-lie: knee rolling).

25 Crook-lie: pelvic tilt, keeping shoulders flat and knees together, raise knees to chest, roll knees to the left then to the right, return to midline.

Section III Head, Trunk and Leg Movements Performed Simultaneously ('trunk plus legs')

Code numbers 26-31

26 Supine: pelvic tilt, keeping chin on chest, raise left leg to 45 degrees. (supine: chin on chest, single leg raise).

28 Supine: pelvic tilt, arms forward, curl whilst raising leg to 45 degrees.

31 Supine: pelvic tilt, arms forward, curl diagonally taking both hands to outside of left leg which is simultaneously raised to 45 degrees. As above to the right.

APPENDIX III

The assessment of abdominal muscle exercises.

Information on the electromyographic activity associated with every exercise in the main series is given in the tables (a), (b), (c), (d)

Each table represents the results for one muscle: (a) left rectus abdominis (b) left external oblique (c) left internal oblique (d) right external oblique.

On each table the first column gives the code number of the exercise (for detail see Appendix II).

The next four sections represent the results from the four subject categories: non-pregnant, 38 weeks gestation, 5 days postpartum and 6 weeks postpartum.

The columns within each section headed "H", "M" and "L", depict the number of subjects out of thirty showing 'highest', 'middle' and 'lowest' grade electromyographic activity respectively.

Note there is no ranking order in these total results. For ranking information see Table 1.

(a) LEFT RECTUS ABDOMINIS MUSCLE

Exercise Code No.	Non-pregnant			38 weeks Gestation			5 days Postpartum			6 weeks Postpartum		
	H	M	L	H	M	L	H	M	L	H	M	L
1	4	22	4	20	7	3	17	12	1	1	24	5
2	7	19	4	21	7	2	8	15	7	3	21	6
3	3	21	6	22	7	1	15	15	0	5	19	6
4	2	25	3	18	10	2	4	22	4	0	27	3
5	9	19	2	20	10	0	16	11	3	8	20	2
6	25	5	0	16	13	1	15	9	5	23	5	2
8	17	12	1	15	8	7	15	12	3	8	16	6
9	1	18	11	17	11	2	12	17	1	4	21	5
10	1	3	26	3	8	19	2	10	18	0	9	21
12L	4	16	10	15	9	6	6	21	3	4	21	5
12R	5	21	4	18	12	0	5	20	5	3	24	3
13L	3	16	11	13	13	4	1	22	7	2	18	10
13R	6	13	11	14	15	1	7	18	5	4	18	8
14L	4	14	12	7	13	10	6	19	5	0	19	11
14R	4	9	17	3	11	16	0	13	17	0	10	20
16L	5	13	12	5	14	11	2	22	6	1	18	11
16R	1	9	20	3	7	20	1	14	15	0	6	24
18	0	0	30	0	1	29	0	0	30	0	1	29
21	6	15	9	2	10	18	4	13	13	2	13	15
22L	0	2	28	0	2	28	0	0	30	0	4	26
22R	0	2	28	0	0	30	0	1	29	0	4	26
24	0	1	29	0	0	30	0	0	30	0	0	30
25	0	1	29	0	4	26	0	3	27	0	0	30
26	1	7	22	2	6	22	0	5	25	0	2	28
28	3	22	5	19	10	1	4	24	2	3	20	7
31L	3	17	10	13	12	5	0	25	5	2	18	10
31R	5	20	4	17	10	3	2	26	2	3	20	7

H = *highest grade electromyographic activity shown by this number of subjects out 30.*
M = *middle grade electromyographic activity shown by this number of subjects out of 30.*
L = *lowest grade electromyographic activity shown by this number of subjects out of 30.*

APPENDIX III *(cont)*

(b) LEFT EXTERNAL OBLIQUE MUSCLE

Exercise Code No.	Non-pregnant			38 weeks Gestation			5 days Postpartum			6 weeks Postpartum		
	H	M	L	H	M	L	H	M	L	H	M	L
1	8	15	7	7	7	16	4	17	9	1	18	11
2	0	15	5	4	16	10	3	14	13	4	17	9
3	5	13	12	7	13	10	0	20	10	3	17	10
4	4	20	6	4	20	6	5	15	10	2	19	9
5	12	14	4	5	16	9	4	12	14	2	23	5
6	14	13	3	2	14	14	4	10	16	5	14	11
8	17	11	2	9	13	8	5	10	15	10	13	7
9	3	18	9	11	17	2	7	20	3	3	20	7
10	1	8	21	9	11	10	2	14	14	1	10	19
12L	4	17	9	6	10	14	1	13	16	3	12	15
12R	15	12	3	17	12	1	7	15	8	10	14	6
13L	1	11	18	6	12	12	0	11	19	1	15	14
13R	10	14	6	15	14	1	9	13	8	5	20	5
14L	13	11	6	22	7	1	17	11	2	10	13	7
14R	3	3	24	0	5	25	0	5	25	0	2	28
16L	9	18	3	14	15	1	19	9	2	12	12	6
16R	2	5	23	0	5	25	1	3	26	0	5	25
18	0	3	27	0	0	30	0	2	28	0	3	27
21	5	15	10	9	7	14	5	18	7	3	13	14
22L	1	5	24	0	3	27	0	2	28	0	7	23
22R	8	9	13	2	11	17	0	17	13	7	11	12
24	0	5	25	0	2	28	0	4	26	0	6	24
25	0	12	18	5	8	17	8	14	8	3	10	17
26	1	6	23	1	2	27	0	0	30	0	4	26
28	0	24	6	9	13	8	1	17	12	2	16	12
31L	1	15	14	4	16	10	1	7	22	2	13	15
31R	15	12	3	13	10	7	4	18	8	4	20	6

H = *highest grade electromyographic activity shown by this number of subjects out 30.*
M = *middle grade electromyographic activity shown by this number of subjects out of 30.*
L = *lowest grade electromyographic activity shown by this number of subjects out of 30.*

APPENDIX III *(cont)*

(c) LEFT INTERNAL OBLIQUE MUSCLE

Exercise Code No.	Non-pregnant			38 weeks Gestation			5 days Postpartum			6 weeks Postpartum		
	H	M	L	H	M	L	H	M	L	H	M	L
1	6	17	7	9	15	6	11	15	4	3	21	6
2	5	19	6	6	19	5	3	17	10	5	21	4
3	11	17	12	6	17	7	7	19	4	4	22	4
4	5	15	10	5	15	10	4	19	7	4	24	2
5	9	14	7	6	19	5	8	13	9	6	22	2
6	16	11	3	5	16	9	6	12	12	10	18	2
8	15	9	6	4	13	13	4	16	10	11	16	3
9	2	14	14	9	16	5	9	16	5	5	21	4
10	0	7	23	3	7	20	0	10	20	0	5	25
12L	5	16	9	12	13	5	13	11	6	5	17	8
12R	5	17	8	4	19	7	3	17	10	5	19	6
13L	2	14	14	11	12	7	6	14	10	3	17	10
13R	3	16	11	4	15	11	4	16	10	1	19	10
14L	2	14	14	10	15	5	5	16	9	3	14	13
14R	3	10	17	0	6	24	1	7	22	0	0	22
16L	1	15	14	4	15	11	4	15	11	1	16	13
16R	3	12	15	0	4	26	2	8	20	1	5	24
18	2	7	21	0	4	26	0	1	29	0	6	24
21	12	11	7	7	20	3	9	13	8	5	14	11
22L	6	6	18	2	10	18	1	5	24	3	10	17
22R	2	5	23	0	3	27	0	1	29	0	2	28
24	0	1	29	0	2	28	1	0	29	0	0	30
25	3	3	24	4	5	21	3	10	17	0	6	24
26	0	10	20	1	6	23	0	5	25	1	2	27
28	5	18	7	16	11	3	7	18	5	4	21	5
31L	3	21	6	16	12	2	6	19	5	3	20	7
31R	9	12	9	4	17	9	2	15	13	3	17	10

H = *highest grade electromyographic activity shown by this number of subjects out 30.*
M = *middle grade electromyographic activity shown by this number of subjects out of 30.*
L = *lowest grade electromyographic activity shown by this number of subjects out of 30.*

APPENDIX III *(cont)*

(d) RIGHT EXTERNAL OBLIQUE MUSCLE

Exercise Code No.	Non-pregnant			38 weeks Gestation			5 days Postpartum			6 weeks Postpartum		
	H	M	L	H	M	L	H	M	L	H	M	L
1	6	15	9	12	10	8	11	14	5	2	20	8
2	6	19	5	11	10	9	4	15	11	5	19	6
3	0	18	12	13	13	4	9	16	5	4	18	8
4	1	23	6	10	14	6	6	16	8	2	20	8
5	7	21	2	9	19	2	7	12	11	3	21	6
6	17	11	2	8	11	11	8	10	12	12	12	6
8	16	14	0	10	9	11	7	13	10	13	14	3
9	0	20	10	14	12	4	7	21	2	5	19	6
10	0	4	26	5	6	19	2	13	15	1	10	19
12L	11	16	3	13	14	3	9	16	5	9	17	4
12R	3	17	10	9	13	8	2	16	12	5	19	6
13L	6	16	8	15	13	2	7	16	7	6	16	8
13R	1	14	15	7	15	8	2	13	15	4	17	9
14L	1	4	25	1	2	27	1	5	24	0	8	22
14R	4	18	8	9	20	1	13	15	2	7	21	2
16L	1	4	25	1	6	23	1	6	23	1	5	24
16R	6	17	7	14	10	6	11	17	2	8	16	6
18	1	1	28	0	1	29	0	1	29	0	2	28
21	7	16	7	3	11	16	4	17	9	3	12	15
22L	7	8	15	1	9	20	3	11	16	4	12	14
22R	0	4	26	0	1	29	0	1	29	1	4	25
24	0	3	27	0	0	30	0	2	28	0	0	30
25	1	5	25	3	5	22	7	15	8	2	12	16
26	0	2	28	1	3	26	0	1	29	0	2	28
28	4	22	4	19	7	4	6	17	7	1	22	7
31L	8	17	5	16	10	4	3	16	11	6	17	7
31R	3	21	6	9	16	5	2	14	14	3	19	8

H = *highest grade electromyographic activity shown by this number of subjects out 30.*
M = *middle grade electromyographic activity shown by this number of subjects out of 30.*
L = *lowest grade electromyographic activity shown by this number of subjects out of 30.*

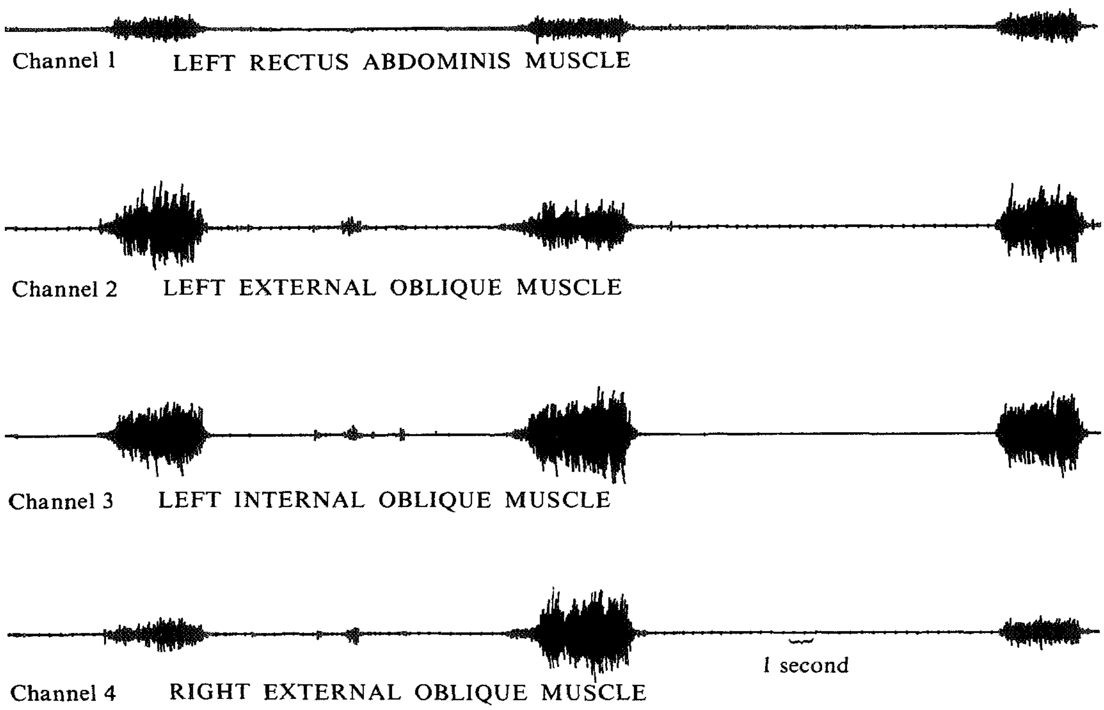


FIGURE 1

SAMPLE ELECTROMYOGRAPHIC TRACING

Simultaneous recording from four different muscles:
- channel 1: left rectus abdominis muscle
- channel 2: left external oblique muscle
- channel 3: left internal oblique muscle
- channel 4: right external oblique muscle

Each channel shows the suface electromyograms (summated electrical activity of many motor units) for three exercises. It is part of a long recording of responses to twenty-one exercises.

It is valid to compare amplitude and intensity of response within a channel, but not between channels: refer Methods (3).

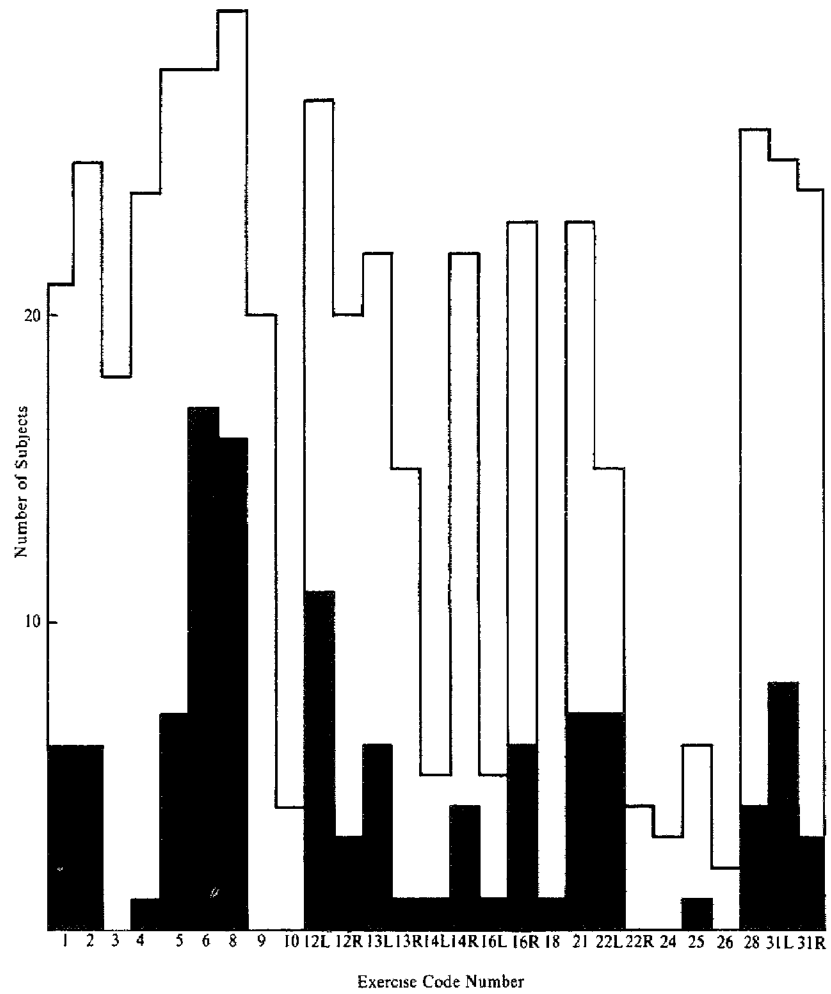
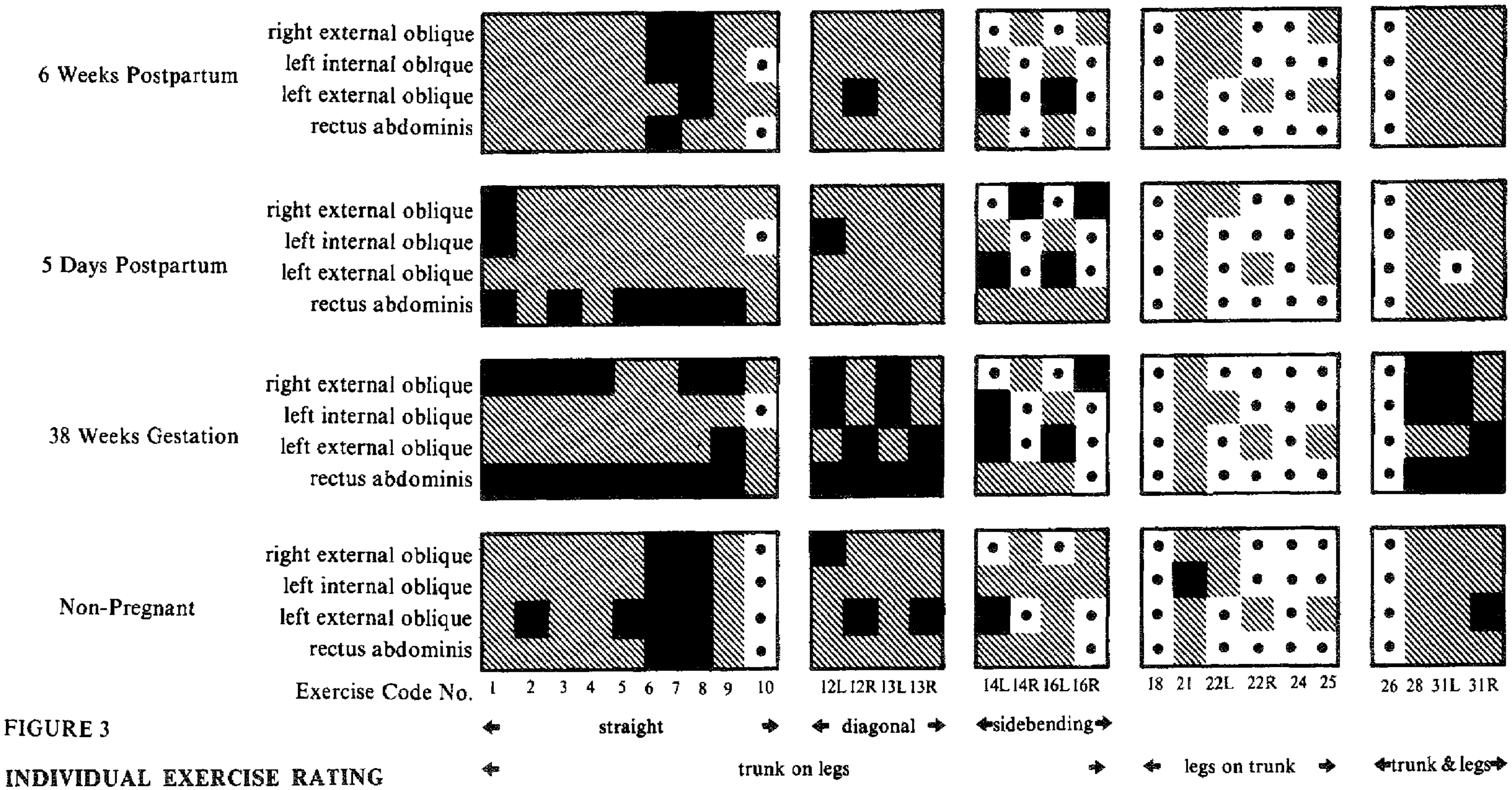


FIGURE 2
SAMPLE BAR CHART

Legend Figure 2

Sample bar chart

Each vertical column represents the experimental results for one of the twenty-one exercises in the main series. The detail of each exercise is given in Appendix II. Solid blocks above a given exercise code number represent the number of subjects out of thirty for whom that exercise was assessed as having 'highest grade' electromyographic activity. The corresponding outline above the solid block represents the number of subjects out of thirty assessed as having 'middle grade' electromyographic activity. The space remaining above the outline represents the number out of thirty having 'lowest grade' electromyographic activity. The sample shown is for one of the four muscles tested in one of the four subject categories. The complete results of the main series (expressed in numerical rather than graphic form) are given in Appendix III.



Good ■ 10 or more patients/30 highest grade EMG

Moderate ▨ 10 or more patients/30 highest grade & middle grades EMG

Poor ⊡ Less than 10 patients/30 highest and middle grades EMG

FIGURE 3

INDIVIDUAL EXERCISE RATING

This diagram is based on the total data of the main series. As in Figure 2, each vertical column represents results from the exercise whose code number is inscribed under that column, but in Figure 3 the data is derived from all four muscles and all four subject categories.

Legend to Table I

This table shows the exercises which have been found to be most effective for the abdominal muscles in the four separate subject categories. In each section, the exercise code numbers, corresponding to the Exercise List in Appendix II, are on the left. They are ranked in order of merit as far as mathematically possible In the bracket following the exercise code number, the first figure indicates the number of subjects out of the 30 tested in the category for whom that exercise was assessed as having 'highest grade' electromyographic activity. The second figure indicates the number assessed as having 'middle grade' and the third figure as 'lowest grade' electromyographic activity.

TABLE I "MERIT" RANKING OF ABDOMINAL MUSCLE EXERCISES BASED ON ELECTROMYOGRAPHIC ASSESSMENT

Muscle		Non-pregnant		38 weeks Gestation		5 days Postpartum		6 weeks Postpartum
	Ex Code No.		Ex. Code No		Ex. Code No		Ex. Code No	
	6	(25 + 5 + 0)	3	(22 + 7 + 3)	1	(17 + 12 + 1)	6	(23 + 5 + 2)
Left	8	(17 + 12 + 1)	2	(21 + 7 + 2)	5	(16 + 11 + 3)	5	(8 + 20 + 2)
Rectus	5	(9 + 19 + 2)	5	(20 + 10 + 0)	3	(15 + 15 + 0)	8	(8 + 16 + 6)
Abdominis	2	(7 + 19 + 4)	1	(20 + 7 + 3)	8	(15 + 12 + 3)		
Muscle	31R	(6 + 20 + 4)	28	(19 + 10 + 1)	6	(15 + 9 + 6)		
			12R	(18 + 12 + 0)	9	(12 + 17 + 1)		
			4	(18 + 10 + 2)				
			9	(17 + 11 + 1)				
			31R	(17 + 10 + 3)				
			6	(16 + 13 + 1)				
			12L	(15 + 9 + 6)				
			8	(15 + 8 + 7)				
			13R	(14 + 15 + 1)				
			13L	(13 + 13 + 4)				
			31L	(13 + 12 + 5)				
	8	(17 + 11 + 2)	14L	(22 + 7 + 1)	16L	(19 + 9 + 2)	16L	(12 + 12 + 6)
	12R	(15 + 12 + 3)	12R	(17 + 12 + 1)	14L	(17 + 11 + 2)	12R	(10 + 14 + 6)
Left	31R	(15 + 12 + 3)	13R	(15 + 14 + 1)			14L	(10 + 13 + 7)
External	6	(14 + 13 + 3)	16L	(14 + 15 + 1)			8	(10 + 13 + 7)
Oblique	14L	(13 + 11 + 6)	31R	(13 + 10 + 7)				
Muscle	5	(12 + 14 + 4)	9	(11 + 17 + 2)				
	2	(10 + 15 + 5)						
	13R	(10 + 14 + 6)						
	6	(16 + 11 + 3)	31L	(16 + 12 + 2)	12L	(13 + 11 + 6)	8	(11 + 16 + 3)
	8	(15 + 9 + 6)	28	(16 + 11 + 3)	1	(11 + 15 + 4)	6	(10 + 18 + 2)
Left	21	(12 + 11 + 7)	12L	(12 + 13 + 5)	9	(9 + 16 + 5)	5	(6 + 22 + 2)
Internal	5	(9 + 14 + 7)	13L	(11 + 12 + 7)	21	(9 + 13 + 8)	2	(5 + 21 + 4)
Oblique	31R	(9 + 12 + 9)	14L	(10 + 15 + 5)	5	(8 + 13 + 9)	9	(5 + 21 + 4)
Muscle			9	(9 + 16 + 5)	3	(7 + 19 + 4)	12R	(5 + 19 + 7)
			1	(9 + 15 + 6)	28	(7 + 18 + 5)		
			21	(7 + 20 + 3)				
	6	(17 + 11 + 2)	28	(19 + 7 + 4)	14R	(13 + 15 + 2)	8	(13 + 14 + 3)
	8	(16 + 14 + 0)	31L	(16 + 10 + 4)	16R	(11 + 17 + 2)	6	(12 + 12 + 6)
Right	12L	(11 + 16 + 3)	13L	(15 + 13 + 2)	1	(11 + 14 + 5)	12L	(9 + 17 + 5)
External			9	(14 + 12 + 4)	12L	(9 + 16 + 5)	16R	(8 + 16 + 6)
Oblique			16R	(14 + 10 + 6)	3	(9 + 16 + 5)	14R	(7 + 21 + 2)
Muscle			12L	(13 + 14 + 3)				
			3	(13 + 13 + 4)				
			1	(12 + 10 + 8)				
			2	(11 + 10 + 9)				
			4	(10 + 14 + 6)				
			8	(10 + 9 + 11)				

Legend Figure 4

Changes in electromyographic responses of the rectus abdominis muscle during pregnancy and the puerperium

In each of the three parts (a), (b) and (c), each column represents an exercise in the main series, carried out in the same order as in Figure 2 and 3. In Figure 4, the interest is not so much in the individual exercises, but in the comparison of groups of exercises (for example, 'trunk on legs' versus 'legs on trunk', as indicated beneath the columns) and how the distribution of effective exercises varies during pregnancy and the puerperium.

The height of each column represents the number of subjects out of thirty in whom 'highest grade' electromyographic activity was recorded for that particular exercise. The hatched columns represent:

(a) subjects in the 38 weeks gestation category.
(b) subjects in the 5 days postpartum category.
(c) subjects in the 6 weeks postpartum category.

In each instance, the distribution for non-pregnant subjects is superimposed (thick outline).

It will be noted in (a) that there is a much wider distribution of effective exercises for rectus abdominis muscle in the 38 weeks gestation category than in non-pregnant subjects, that is, many more exercises of the 'trunk on legs' and 'trunk plus legs' groups produce 'highest grade' electromyographic activity in a large number of subjects. A progressive return toward the non-pregnant pattern by the postpartum subjects is indicated in (b) and (c).

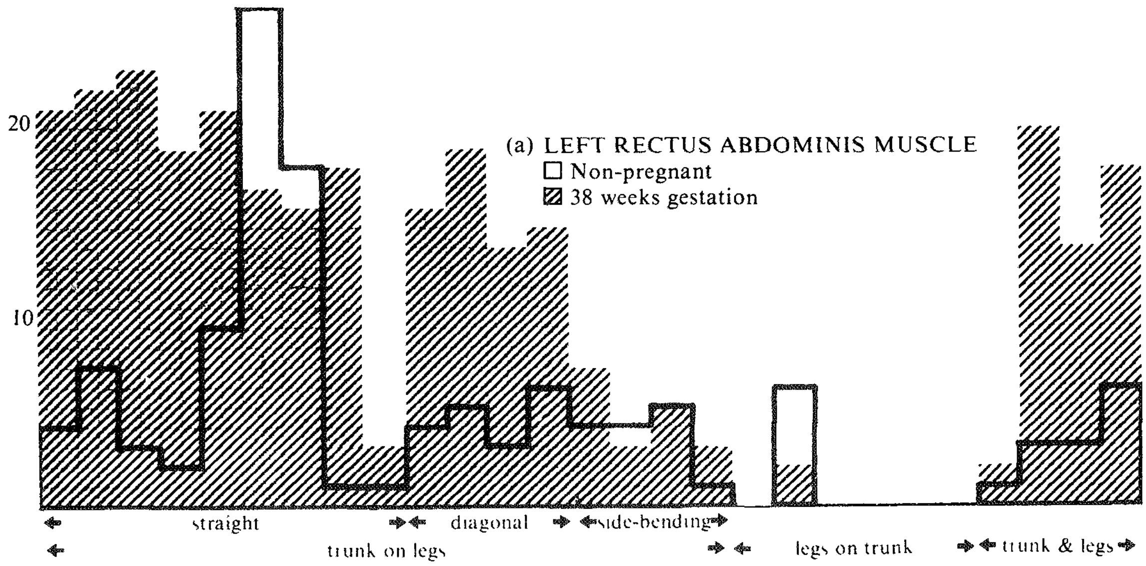


FIGURE 4

ELECTROMYOGRAPHIC CHANGES DURING AND AFTER PREGNANCY

FIGURE 4 *(cont)*